Reprinted from "Bulletin of Marine Science" Volume 56, 1995, pp. 547-568, Epperly et al.: Winter distribution of sea turtles in the vicinity of Cape Hatteras and their interactions with the summer flounder trawl fishery. With permission from Rosenstiel School of Marine and Atmospheric Science of the University of Miami.

ERRATA/UPDATE

PAGE 563:
Figure 12 references are transposed in the text (not Figure Legend). Below are the corrections.

existing reference to Fig. 12C should be to Fig. 12B
existing reference to Fig. 12D should be to Fig. 12C
existing reference to Fig. 12B should be to Fig. 12D

LITERATURE CITED:
Several papers cited as in press have now been published. The updated citations follow.

Epperly et al., In Press-a was published in 1995 in *Fishery Bulletin* 93:254-261.

Epperly et al., In Press-b was published in 1995 in *Conservation Biology* 9:383-393.

Pietrafesa et al., In Press was published in 1994 in *Deep-Sea Research II* 41:365-389.

FUTURE REFERENCE:
Another aspect of this research is scheduled for publication in 1996 in *Bulletin of Marine Science*, Vol. 59(1). The current citation follows.

Epperly, S.P., J. Braun, A.J. Chester, F.A Cross, J.V. Merriner, P.A. Tester, and J.H. Churchill. In Press. Beach strandings as an indicator of at-sea mortality of sea turtles. Bull. Mar. Sci.

WINTER DISTRIBUTION OF SEA TURTLES IN THE VICINITY OF CAPE HATTERAS AND THEIR INTERACTIONS WITH THE SUMMER FLOUNDER TRAWL FISHERY

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WINTER DISTRIBUTION OF SEA TURTLES IN THE VICINITY OF CAPE HATTERAS AND THEIR INTERACTIONS WITH THE SUMMER FLOUNDER TRAWL FISHERY

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ABSTRACT

Aerial surveys of North Carolina offshore waters between Cape Lookout and the North Carolina/Virginia state line were conducted November 1991–March 1992 to determine the abundance of sea turtles in the area where a trawl fishery for summer flounder was active, and to relate the distribution of turtles to physical oceanographic processes. Turtles were sighted throughout the winter as far north as Oregon Inlet. Individual surveys yielded surface density estimates greater than 12 turtles·100 km^{-2}, depending on the method of analysis. The distribution of turtles appeared to be related to water temperature, with turtles being mostly in waters ≥11°C. Favorable temperature and depth regimes for sea turtles occur throughout the winter along the western edge of the Gulf Stream from the vicinity of Cape Hatteras southward. The nearshore waters of Raleigh Bay, more than any other nearshore area of the South Atlantic Bight, are affected in the winter by the warm, fast-moving Gulf Stream and its frontal eddies that impinge upon and override the narrow continental shelf. Characteristically the waters in the vicinity of Cape Hatteras are warmer in the winter than nearshore areas to the south. The narrowness of the continental shelf and the influence of the Gulf Stream on these nearshore regions serve to concentrate sea turtles emigrating from nearshore waters in the Middle Atlantic Bight and Pamlico and Core Sounds in the late fall and early winter. Thus, sea turtles can be at greater risk for interaction with fishing activity on the continental shelf near Cape Hatteras, during the winter, than in any other area in the South Atlantic Bight. The summer flounder fishery, operating between Cape May, New Jersey and Cape Lookout, North Carolina during November 1991–February 1992, was monitored for interactions with sea turtles. Observers were aboard nearly 6% of the reported trips landed in Virginia and North Carolina. The sea turtle catch comprised loggerheads (60%), Kemp's ridleys (36%), greens (2%), and a hawksbill (1%). The catch of Kemp's ridleys during November–December 1991 south of Cape Hatteras was high (N = 26). Overall turtle catch rates were similar to those reported for the Atlantic shrimp fishery, but catch rates south of Cape Hatteras were 6–8 times higher than catch rates north of the Cape. A total of 1,063 turtles was estimated to have been caught November 1991–February 1992, and 89–181 were estimated to have died as a result of the trawl fishery. None of the turtles tagged during this study was recaptured during the study period, but three were recaptured subsequently; one had been resuscitated. Trawl activity was aggregated, and a number of turtles required resuscitation after 60 min tows. Sea turtle conservation regulations are needed for this fishery because the turtle/fishery interaction is great (>1,000 turtles estimated caught), the proportion caught that is Kemp's ridleys is high (35%), and the physical processes that concentrate the sea turtles on the fishing grounds are operable every winter.

Sea turtles emigrate from coastal waters of the Middle Atlantic Bight of the United States, moving southward towards Cape Hatteras, North Carolina in the fall (Shoop and Kenney, 1992; Keinath, 1993). Turtles inhabiting North Carolina inshore waters emigrate from the sounds by early winter (Epperly et at., in press-b). Several major turtle stranding events have occurred on the northern coast of North Carolina during this period of migration. These events coincide in time and

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space with the activity of a trawl fishery for summer flounder, *Paralichthys dentatus* (Crouse, 1985; Mid-Atlantic Fishery Management Council, 1988).

Because of suspected interactions between this fishery and protected sea turtles, the National Marine Fisheries Service (NMFS) and the North Carolina Division of Marine Fisheries (NCDMF) developed a cooperative plan to monitor the summer flounder trawl fishery in the winter 1991–1992. The purpose of the study was three-fold: 1) to determine the abundance of sea turtles on the fishing grounds, 2) to determine the extent of fishery/sea turtle interactions, and 3) to relate the distribution of turtles to water temperature and other physical processes. Monitoring activities involved both fishery-dependent and fishery-independent methods and included at-sea observer sampling of the fleet, aerial surveys for turtles and for fleet location, and examination of near real-time sea surface temperature (SST) imagery provided through the NOAA Coastal Ocean Program's CoastWatch Project for comparison with observed occurrences of sea turtles. Tow time restrictions of 75 min were imposed on vessels operating south of Cape Charles, Virginia to protect sea turtles.

Study Area

The western North Atlantic study area was divided by Cape Hatteras (35°14′N × 75°32′W), which separates the eastern United States continental margin into two major provinces: the South Atlantic Bight (SAB) and the Middle Atlantic Bight (MAB). The SAB is the region betweeen West Palm Beach, Florida and Cape Hatteras, North Carolina; the MAB extends northward, from Cape Hatteras to Long Island, New York. The study area included the northern region of the SAB known as the Carolina Capes (Raleigh, Onslow and Long Bays) and the southern portion of the MAB (Fig. 1). The Carolina Capes region is characterized by extensive shoals at Capes Hatteras, Lookout and Fear, and by a shallow, narrow continental shelf. The Gulf Stream, the easternmost edge of the SAB, flows northeastward parallel to the continenal shelf edge. Between Capes Hatteras and Lookout, it is within 30–63 km of shore. North of Cape Hatteras the continental shelf widens and deepens and the Gulf Stream veers to the northeast, moving seaward of the continental margin.

Materials and Methods

Fishery-Dependent.—State and Federal port agents in Virginia and North Carolina recorded landings and the number of trips reported by the flounder trawl fishery (Table 1). In Virginia, the fleet off-loaded catches mainly in the Hampton, Va. area; in North Carolina the major ports were Wanchese, Beaufort-Morehead City area, and ports along the western perimeter of Pamlico Sound (Fig. 1).

Observers aboard flounder trawl vessels monitored the type and size of nets used, beginning and ending location, water depth, sea surface temperature, and duration of each tow, and documented all incidental captures of sea turtles. Captured sea turtles were identified, measured, individually tagged and released. Carapace measurements were standard measures of over-the-curve length (OCCL) (Pritchard et al., 1982). Turtles were double-tagged (National Band and Tag Company, style Inconel 681-C) on the rear flippers. If necessary, turtles were resuscitated. Generally, dead turtles were stored on ice and returned to shore for necropsy by researchers at the Virginia Institute of Marine Science.

Trawling effort was standardized following methods of Henwood and Stuntz (1987) because tow durations and net sizes differed, and catch rates were calculated. Catch-per-unit effort estimates did not include effort and catch by TED-equipped nets. To estimate the total number of turtles caught during the monitoring period, stratified random survey techniques were used (Cochran, 1977). Data were stratified by the ports of landing and time periods because it appeared that there were some differences in the characteristics of the fleet, such as vessel size, trip duration, areas fished, etc. Turtle catch was compiled for vessels landing in North Carolina and Virginia ports separately for the November–December 1991 and the January–February 1992 time periods. Within each of the four strata, catch estimates were based on the proportion of observed trips to the total trips reported (Table 1). Underlying assumptions were that the reported total number of trips within strata were accurate and that the observed trips were a random sample (i.e., representative in location of fishing, duration of trip, size and rigging of nets, length of tow, catch, care of turtles, resuscitation success, etc.) of the entire fleet landing in the same area during the same time period. There were no performance data available for the fleet at large with which these assumptions could be evaluated. Ninety-five percent confidence intervals for these estimates of total catch were derived using bootstrapping, a non-para-

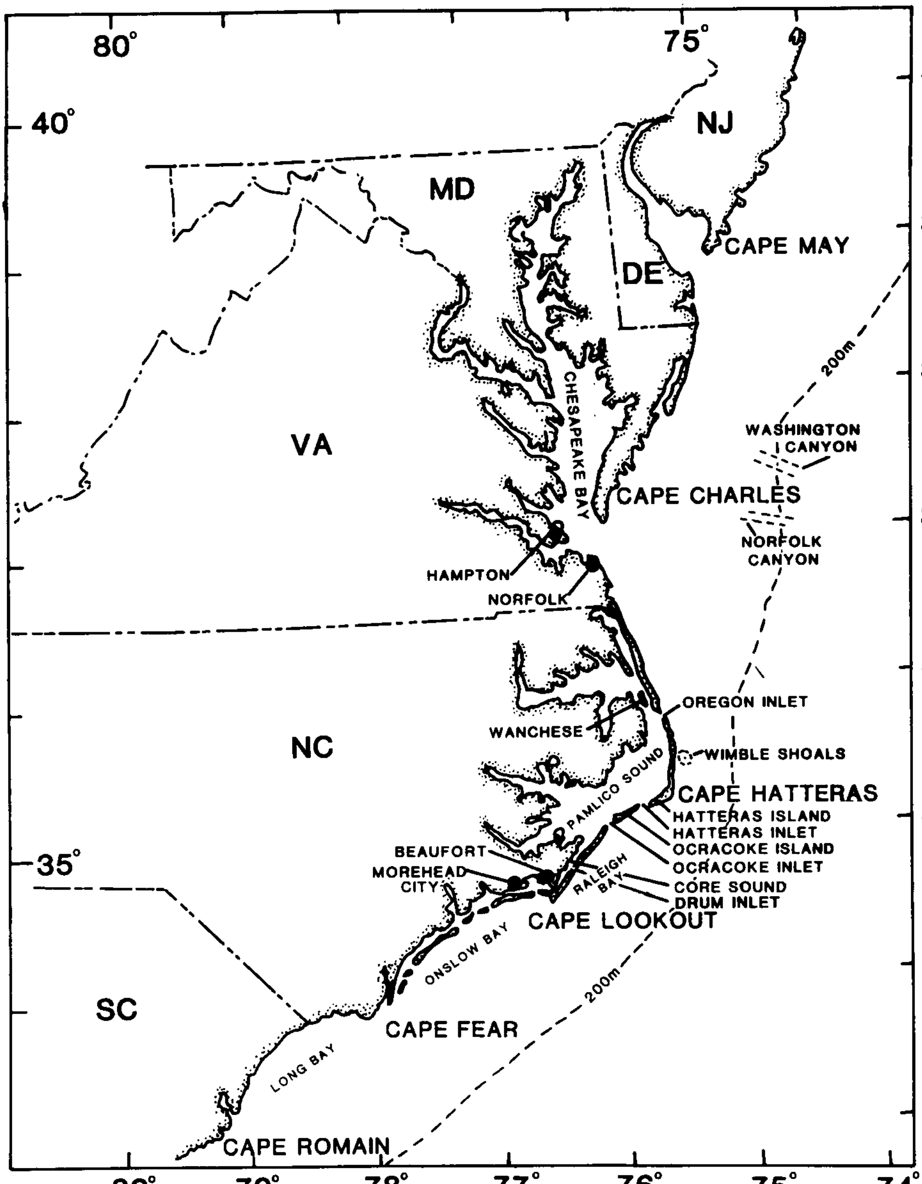


Figure 1. The central Atlantic coast of the United States.

metric, simulated resampling technique (Efron and Gong, 1983; Efron and Tibshirani, 1986). Trips were resampled (N = 10,000 iterations) within the hypothetical population of each stratum, which was constructed from the observer data.

Lethal take of sea turtles and 95% confidence intervals for total mortality were estimated for the flounder trawl fishery from November 1991–February 1992 using the same stratified random and bootstrapping techniques described above. Two analyses were conducted. The first assumed that all resuscitated turtles lived. The second, conducted to provide an estimate of the upper limit of mortality, assumed that all resuscitated turtles later died from the trauma (Magnuson et al., 1990).

Table 1. Monthly summary of summer flounder trawl fishery trips reported landed in North Carolina and Virginia, and number of trips with observers, October 1991–April 1992 (K. Harris, pers. comm.). Observers were aboard 42 of the 1,098 trips reported.

	North Carolina		Virginia	
Month	Number trips reported	Number observed trips	Number trips reported	Number observed trips
October 1991	24	0	85	0
November 1991	68	2	71	4
December 1991	113	11	79	0
January 1992	80	14	133	6
February 1992	57	2	113	3
March 1992	56	0	132	0
April 1992	27	0	60	0

Fishery-Independent.—Aerial surveys for sea turtles followed methodology similar to that established for surveys of Core and Pamlico Sounds (Epperly et al., in press-a). The coastal area between the North Carolina/Virginia State line and Cape Lookout was partitioned into five zones (Fig. 2); approximately 10% visual coverage of a selected zone could be completed during a 3-h flight. Survey zones chosen for any given day were based on the known location of the fishing fleet, reports of incidental turtle captures, and examination of sea surface temperature data. Initially, surveys were flown where the fleet was most active and incidental catches of turtles were greatest. By February, surveys were flown to test hypotheses about turtle associations with oceanographic features. November surveys were conducted within 5.6 km of shore. By early December the flounder trawl fleet was operating frequently >5.6 km from shore, and the surveys were extended to 28 km from shore. All aircraft (Cessna 172, Rockwell Shrike AC-500S Aero Commander, and Cessna 337 Skymaster) allowed a side view of the sea surface; the flight line was not visible. Airspeeds ranged from 185 to 222 km/h at an altitude of 152 m. Turtle sightings in Raleigh, Onslow, and Long Bays also were recorded during

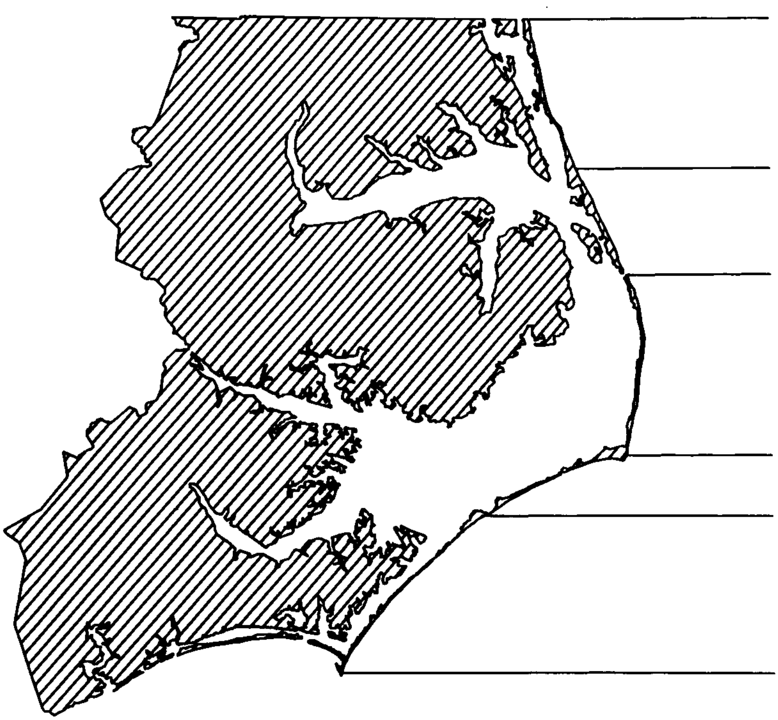


Figure 2. Five aerial survey zones off the northern coast of North Carolina.

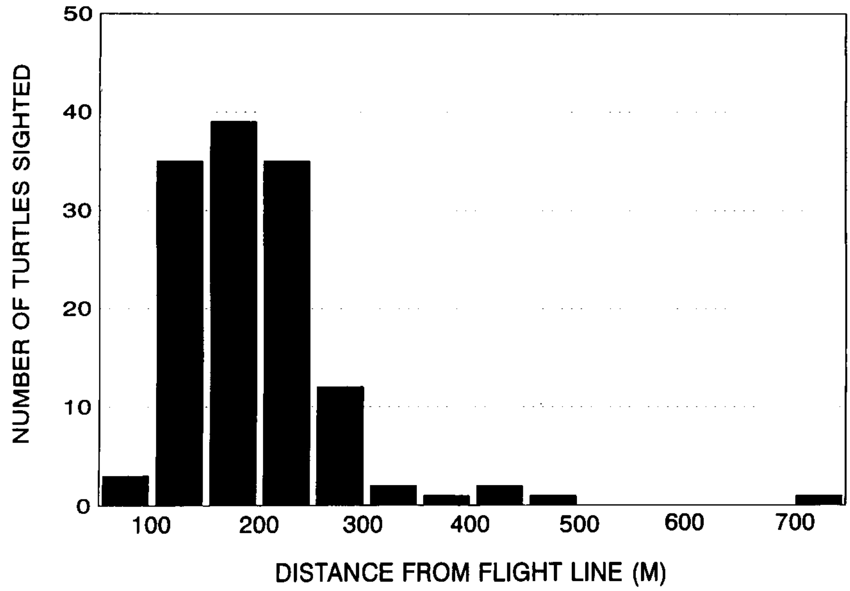


Figure 3. Histogram of distances turtles were sighted from the line of flight in aerial surveys off the northern coast of North Carolina.

concurrent marine mammal surveys of the area by the National Marine Fisheries Service and the New England Aquarium.

The number and density of turtles on the surface of a zone were estimated for the directed turtle surveys (sightings from marine mammal surveys were not used in the calculations of density), using both strip and line transect theory (Epperly et al., in press-a). We constructed a composite histogram for all sighting data (Fig. 3), and empirically determined the strip width over which the probability of sighting a turtle was not reduced by proximity to or distance from the plane. Observations within this strip were used to calculate strip transect estimates of density for each survey. The program TRANSECT (Laake et al., 1979) was used to evaluate the fit of simple, generalized, and non-parametric models to the sighting data, and to estimate f(0), the inverse of one-half the effective strip width. Line transect estimates of density for each survey were calculated using the derived f(0), and variances were calculated for both types of density estimates.

Satellite-derived images of sea surface temperature (SST) and local wind information from the National Weather Service office located at Cape Hatteras (Buxton, N.C.) were used to relate sea turtle distribution to physical oceanographic features. SST imagery was obtained from the advanced very high resolution radiometer (AVHRR) onboard the NOAA-11 polar-orbiting weather satellite. Digital data sets, acquired in near real-time (6–12 h following satellite passage) through the NOAA Coastal Ocean Program's CoastWatch Project, were processed, mapped to a Mercator projection, and analyzed with software developed within NOAA (McClain, 1981; Weaks et al., 1988; Leshkevich et al., 1993). Multichannel atmospheric correlation algorithms (McMillan and Crosby, 1984) produce SST estimates accurate to <1°C in cloud free images (McClain et al., 1985). Images were examined daily between 13 October 1991 and 1 April 1992. Wind speed and direction observations, collected on an hourly basis, were decomposed into u and v vectors and averaged to obtain mean wind speed and direction per day.

Positional errors inherent in the collection of SST data and turtle locations (geocorrection of the image and LORAN, which was used for navigation in the aerial surveys) are similar in magnitude to the resolution of the images (approximately 1.5 km), and considered insignificant when compared with the error associated with the asynchrony between aerial surveys and satellite passes. The effects of temporal deviations were minimized by overlaying aerial survey results with imagery only when images were available for the same day, and by selecting the image that was closest in time to that of the survey (on clear days, imagery was available twice a day). For images taken on the same day, the time of the satellite pass deviated from local apparent noon (the half-way point of aerial surveys) by 1.8–9.1 h. Imagery was always available within 2 d of all surveys.

The track of each transect and the positions of sea turtles sighted from the air were plotted on the

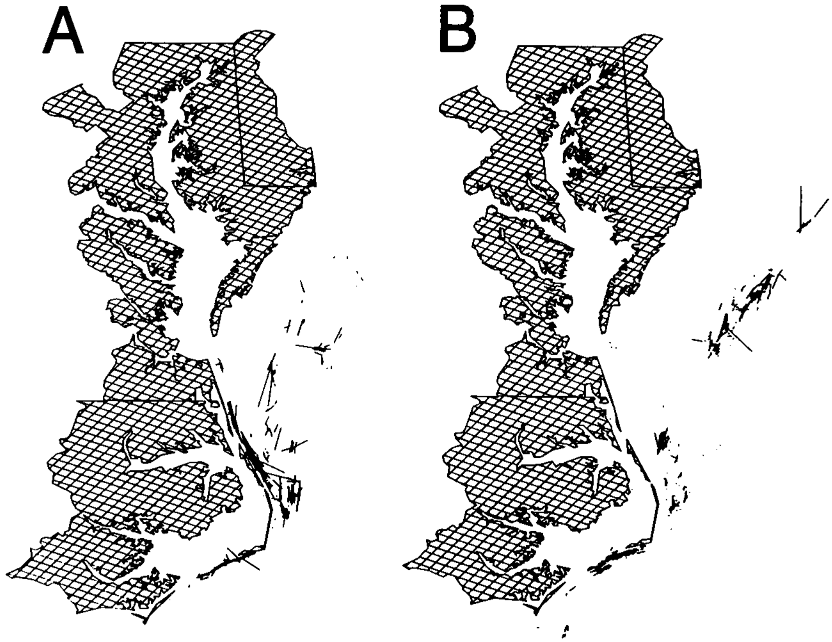


Figure 4. Observed trawl tracks of the summer flounder fishery. A) November–December 1991. B) January–February 1992.

same-day sea surface temperature field. Numbers of sea turtles sighted in each 2°C interval (1°–24°C) were standardized by dividing by the total distance flown (km) in the interval, and are reported as sighting rates. Sea turtle positions obtained from all aerial surveys, including those flown on days without same-day imagery and turtle sightings obtained from the marine mammal surveys, were plotted on the sea surface temperature images closest in time to the surveys to examine the association of turtles with oceanographic features, such as temperature fields, thermal fronts, and the Gulf Stream.

Results

Fishing and Observer Effort.—From October 1991 through April 1992, 1,098 flounder trawling trips were reported landed in North Carolina and Virginia (Table 1). Vessels often fished together, particularly in the Hatteras Bight [the Hatteras Bight is the area south of Cape Hatteras and offshore of Ocracoke and Hatteras Islands] and in the area between Oregon Inlet and Wimble Shoals (Fig. 1). Nearly all hauls in the early season (November–December 1991) were in nearshore waters (<35 m) (Fig. 4A). Some fishing persisted in the Hatteras Bight and on Wimble Shoals through March 1992, but by January–February, most flounder trawling activity had moved northward to deeper water in the vicinity of Norfolk and Washington Canyons (Fig. 4B).

At-sea observations occurred between 11 November 1991 and 20 February 1992. Observers were aboard 42 (5.9%) of the 714 trips reported between November and February (Table 1). Trips ranged from 1 to 15 d in duration, and averaged 5 d (SE = 0.5 d). Observed vessels operated from 34°22.8′N to 38°28.2′N (Fig. 4A, B) and deployed nets 1,397 times (1,058 actual hauls; some hauls were made with two nets) representing 2,745 net hours of actual towing (Table 2). There were 167 hauls observed north of Cape Charles, 466 hauls observed between Cape Charles and Cape Hatteras, and 425 hauls observed south

Table 2. Summary of observer effort in the summer flounder trawl fishery, November 1991–February 1992 (note that a trip may include activity in more than one area)

	Area of fishing		
	North of Cape Charles	Cape Charles to Cape Hatteras	Cape Hatteras to Cape Lookout
November–December 1991			
Trips	2	13	8
Nets towed	13	313	296
Net hours	16	969	319
January–February 1992			
Trips	7	14	17
Nets towed	154	180	441
Net hours	410	430	601

of Cape Hatteras. Most hauls observed north of Cape Charles (83%) were in deep water (>50 m). Observed hauls between Cape Charles and Cape Hatteras usually occurred in waters less than 50 m (96%). Hauls south of Cape Hatteras generally were in waters less than 20 m (87%). Experimental TEDs (those with 15 cm spacing between the bars) and NMFS-certified TEDs (those with 10 cm spacing between the bars) were used on 95 hauls on five of the observed trips; all but three of the TED hauls were made south of Cape Hatteras. Tow duration ranged from 15 min to 6.2 h. Compliance with the 75-min tow restriction was 26% on observed vessels.

Fishery/Sea Turtle Interactions.—Turtles were caught throughout the entire period of monitoring, and 83 turtles were brought aboard trawlers with observers (Table 3, Fig. 5). The sea turtle catch comprised loggerheads (*Caretta caretta*) (60%), Kemp's ridleys (*Lepidochelys kempii*) (36%), greens (*Chelonia mydas*) (2%), and a hawksbill (*Eretmochelys imbricata*) (1%) (Table 3). Most (80%) of the turtles were caught south of Cape Hatteras (Fig. 5), but turtles were caught as far north as 36°12.36′N. Although turtles were caught north of Oregon Inlet before 18 December, no turtles were observed captured north of the inlet after observer coverage resumed in mid January.

Catches north of Cape Hatteras were almost exclusively loggerhead sea turtles (Table 3). Catches south of Cape Hatteras were more diverse, particularly in the first half of the monitoring period, when Kemp's ridley sea turtles accounted for 60% of the catch. No Kemp's ridley turtles were observed after 21 January. Most turtles captured south of Cape Hatteras in January and February 1992 were loggerheads (87%). The last observed capture of a turtle was on 14 February off

Table 3. Species composition of sea turtles in observed trawl catches north and south of Cape Hatteras in the summer flounder fishery, November 1991–February 1992. Deaths are indicated in parentheses. Note that two turtles, a loggerhead and a Kemp's ridley which were caught south of Cape Hatteras in December 1991, were dead prior to their observed capture.

	November–December, 1991		January–February, 1992		
Species	North	South	North	South	Total
Caretta caretta	11 (2)	15 (2)	4	20 (1)	50 (5)
Lepidochelys kempii	2	26 (1)		2	30 (1)
Chelonia mydas		1		1	2
Eretmochelys imbricata		1 (1)			1 (1)
All species	13 (2)	43 (4)	4	23 (1)	83 (7)

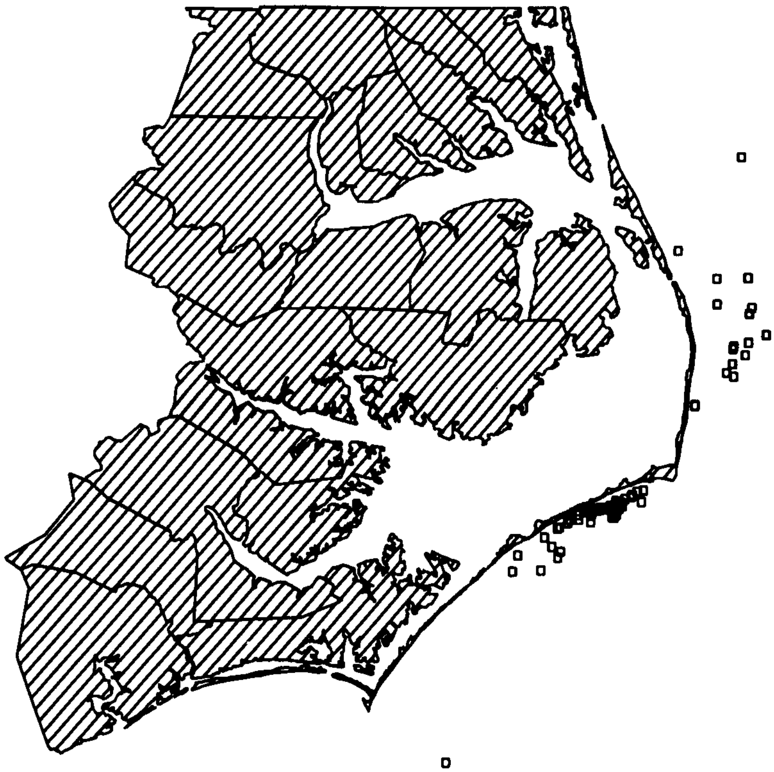
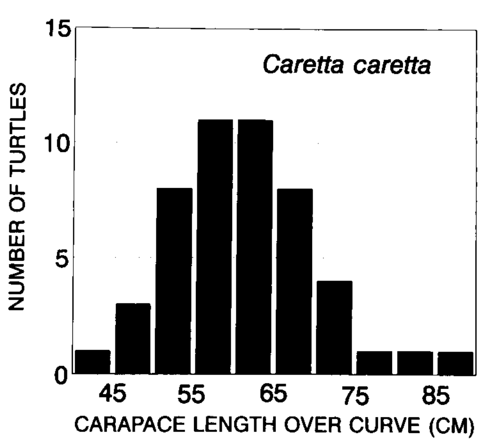


Figure 5. Locations of incidental catches of sea turtles in the summer flounder trawl fishery, November 1991–February 1992.



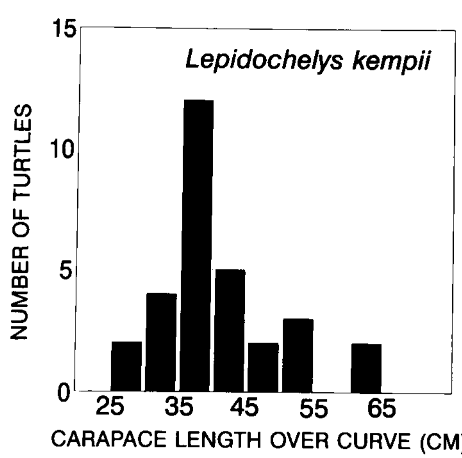


Figure 6. Size frequencies of loggerhead sea turtles, *Caretta caretta*, caught in the summer flounder trawl fishery, November 1991–February 1992.

Figure 7. Size frequency of Kemp's ridley sea turtles, *Lepidochelys kempii*, caught in the summer flounder trawl fishery, November 1991–January 1992.

Table 4. Catch rates of sea turtles (turtles per 100 standard net hours) in the summer flounder trawl fishery, November 1991–February 1992, in nets without TEDs. The unweighted overall catch rate for the entire fishery operating south of Cape Charles was 4.80 turtles per 100 standard net hours.

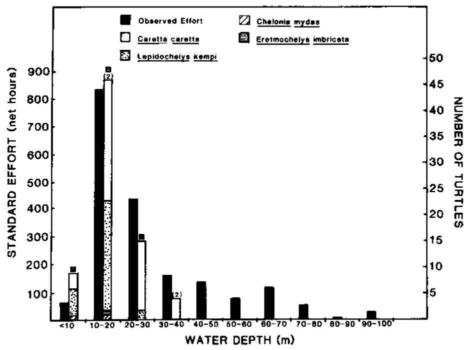
	North of Cape Charles	Cape Charles to Cape Hatteras	Cape Hatteras to Cape Lookout
November–December 1991			
Caretta caretta	0	1.73	6.59
Lepidochelys kempii	0	0.32	10.36
Chelonia mydas	0	0	0.47
Eretmochelys imbricata	0	2.05	17.42
January–February 1992			
Caretta caretta	0	0.93	4.85
Lepidochelys kempii	0	0	0.23
Chelonia mydas	0	0	0.46
All species	0	0.93	5.54
Overall	0	1.67	9.45

Cape Lookout. Captured turtles of all species were immature, except for two loggerhead sea turtles which were >80 cm OCCL. Loggerhead turtles ranged in size from 48–90 cm, and averaged 62 cm (Fig. 6). Kemp's ridley turtles ranged in size from 25–64 cm and averaged 41 cm (Fig. 7). The two green turtles were 26 cm and 28 cm, and the single hawksbill turtle was 30 cm.

Four turtles were captured in TED-equipped nets: three Kemp's ridley turtles (37, 38 and 39 cm OCCL) and the hawksbill turtle were captured in experimental TEDs. No turtles were retained in the 30 hauls made with nets equipped with NMFS-certified TEDs. The hawksbill turtle was the only mortality in a TED-equipped net.

Observers tagged and released 70 turtles. There were no reported recaptures of these turtles during the fishing season, but three turtles were recaptured subsequently. A 39 cm Kemp's ridley, tagged and released on 16 December 1991 just south of Cape Hatteras, was recaptured at 40 cm on 25 March 1992 in Kings Bay Harbor, Georgia. A 36 cm Kemp's ridley, also tagged and released on 16 December 1991 south of Cape Hatteras, was recaptured at 42 cm 25 May 1993 near the mouth of the York River, Virginia. A 50 cm loggerhead, caught in the Wimble Shoals area on 18 December 1991, was resuscitated, tagged and released, and was recaptured 3 July 1992 at the mouth of the Potomac River, Virginia (no size reported). It was re-released alive near its recapture site and was recaptured again nearly a year later in the same area (John Keinath, Virginia Institute of Marine Science, pers. comm.). It was about 56 cm at its most recent recapture. A Kemp's ridley (28 cm straight line carapace length) that had been tagged and released off Long Island, N.Y. on 5 August 1991 (S. J. Morreale, Okeanos Research Foundation, pers. comm.), was reported recaptured during the winter fishing season. It was caught by a trawler not carrying an observer, and released alive east of Cape Hatteras during the last week of November after the tag number was recorded.

The overall catch rate for the entire fishery operating south of Cape Charles, including boats with TEDs, was 4.8 turtles$\cdot$100-h^{-1} of towing. Catch rates south of Cape Hatteras in November–December, however, were greater than 17 turtles$\cdot$100-h^{-1}, and were greater for Kemp's ridley sea turtles than for loggerhead sea turtles (Table 4). Catch rates south of Cape Hatteras were eight times greater than catch rates north of Cape Hatteras prior to 1 January 1992, and were six times greater after 1 January.



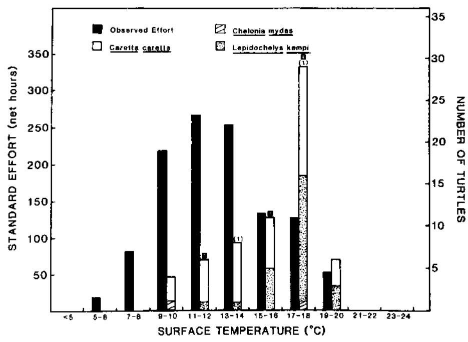


Figure 8. Standard effort and catch of sea turtles in the summer flounder trawl fishery, November 1991–February 1992, as a function of depth. Deaths are indicated in parenthesis and resuscitated turtles are indicated in solid boxes.

Figure 9. Standard effort and catch of sea turtles in the summer flounder trawl fishery, November 1991–February 1992, as a function of water temperature. Deaths are indicated in parenthesis and resuscitated turtles are indicated in solid boxes.

Catch rates were highest in shallow waters (<20 m) (Fig. 8). Turtles were captured in depths from 9 to 34 m; the observed range of depths trawled was 6 to 98 m. Catch rates were highest in warmer waters (>15°C), although turtles were caught in temperatures as low as 10°C (Fig. 9). The water depth and temperature ranges of waters in which Kemp's ridley turtles were captured were

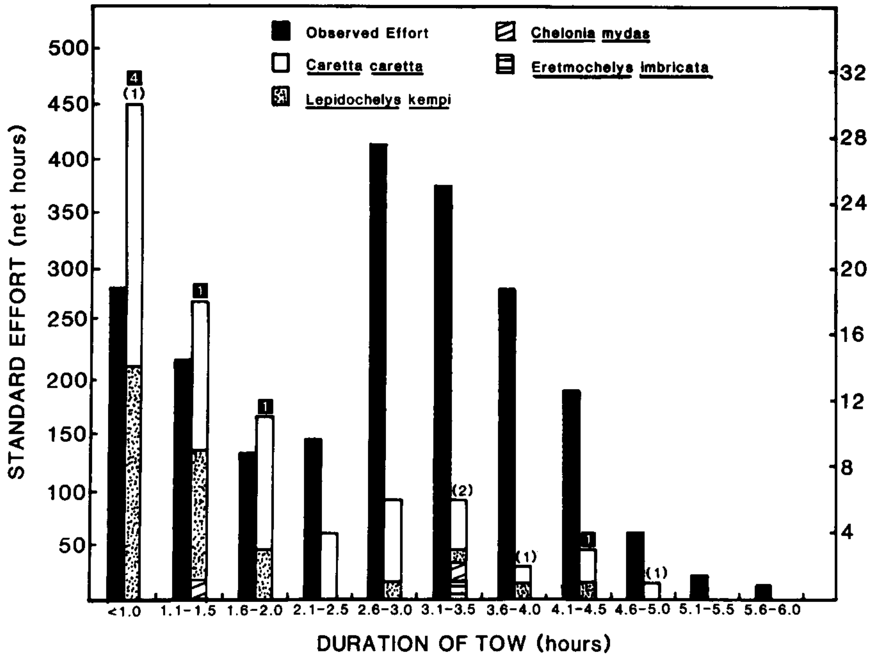


Figure 10. Standard effort and catch of sea turtles in the summer flounder trawl fishery, November 1991–February 1992, as a function of duration of tow. Deaths are indicated in parenthesis and resuscitated turtles are indicated in solid boxes.

Table 5. Estimated total mortality of sea turtles in the summer flounder trawl fishery, November 1991–February 1992 (ranges are given for each estimate based on the assumption that resuscitated turtles all lived or all died)

	State where trip was landed		
	North Carolina	Virginia	Total
November–December 1991			
Caretta caretta	28–56	38–38	66–94
Lepidochelys kempii	0–56	0–0	0–56
Chelonia mydas	0–0	0–0	0–0
Eretmochelys imbricata	14–14	0–0	14–14
January–February 1992			
Caretta caretta	9–17	0–0	9–17
Lepidochelys kempii	0–0	0–0	0–0
Chelonia mydas	0–0	0–0	0–0
Eretmochelys imbricata	0–0	0–0	0–0
All species	51–143	38–38	89–181

narrower than the ranges for loggerhead turtles (Figs. 9, 10). Except for those turtles which were comatose or dead, turtles were generally active when caught.

A total of 1,063 turtles (95% C.I. = 529–1,764) was estimated to have been caught during this portion of the fishery. Based on the stratified mean number of turtles caught per trip, the rate of encounter was approximately 1.5 turtles per trip. Individual stratum values were 4.1 turtles per trip (N.C. Nov.–Dec. 1991), 1.5 turtles per trip (N.C. Jan.–Feb. 1992), 0.3 turtles per trip (Va. Nov.–Dec. 1991), and 0.3 turtles per trip (Va. Jan.–Feb. 1992).

All but seven of the turtles captured were returned to the sea alive. Seven (9%) of those returned to sea had to be resuscitated. No pattern of deaths or comatose turtles with tow duration could be discerned (Fig. 10). Necropsies on five of the dead turtles (the hawksbill and one loggerhead sea turtle were not returned to shore) indicated that the turtles were relatively healthy prior to their deaths, and all had food remains in their digestive tracts. In one instance, the lungs were still inflated; in another, the cause of death was severe trauma, perhaps incurred when the turtle was brought on deck. Two of the mortalities, a partially decomposed loggerhead turtle (71 cm OCCL) and a Kemp's ridley turtle (40 cm OCCL) with rigor mortis, were dead prior to their observed capture. These two turtles were excluded from analysis to determine fishing-induced mortality.

Assuming resuscitated turtles all lived or all died, 89 (95% C.I. = 22–171) and 181 (95% C.I. = 56–342) turtles, respectively, were estimated to have died as a result of the winter trawl fishery for summer flounder during November 1991–February 1992 (Table 5). The mean number of dead or comatose turtles per fishing trip was 0.25 (1 turtle per 4 trips). The individual stratum estimates were 0.7 (N.C. Nov.–Dec. 1991), 0.1 (N.C. Jan.–Feb. 1992), 0.2 (Va. Nov.–Dec. 1991), and 0.0 (Va. Jan.–Feb. 1992).

Aerial Surveys and SST Imagery.—A total of 133 turtles was sighted on the surface during aerial surveys 14 November 1991–30 March 1992. Turtle sighting densities across a strip 0.10–0.25 km from the flight line were similar (Fig 3). Within the dual 0.15 km-wide strips, we assumed that all turtles on the surface were sighted. The effective half-swath of the combined surveys was 0.15 km, given f(0) = 6.70 (SE = 0.34) obtained from the Fourier solution to the sighting probability density function (χ^2 goodness-of-fit test, α = 0.05). Densities obtained from strip and line transect analysis were not appreciably different, but coefficients

Table 6. Strip and line transect estimates of density for sea turtles on the surface of North Carolina nearshore waters from aerial surveys, November 1991–March 1992. Total area of each zone is indicated in parentheses. See Figure 1 for references made to landmarks or inlets.

Survey zone Date	Number of turtles sighted within zone surveyed*	Total distance surveyed (km)	Line transect estimates of density for turtles on surface		Strip transect estimates of density for turtles on surface	
			Turtles·100 km^{-2}	Std. error of mean	Turtles·100 km^{-2}	Std. error of mean
I. Beach to 5.6 km offshore N.C./Va. line to Currituck Bridge (287 km^2)						
15 Nov 1991	0	163	0	—	0	—
Currituck Bridge to Oregon Inlet (223 km^2)						
15 Nov 1991	0	123	0	—	0	—
Oregon Inlet to Cape Hatteras (348 km^2)						
19 Nov 1991	0	197	0	—	0	—
Cape Hatteras to Ocracoke Inlet (266 km^2)						
19 Nov 1991	0	163	0	—	0	—
12 Dec 1991	3	340	0.98	1.19	0.98	0.82
Ocracoke Inlet to Cape Lookout (404 km^2)						
14 Nov 1991	11	237	8.49	4.17	8.45	2.96
II. Beach to 28 km offshore Oregon Inlet to Cape Hatteras (1,711 km^2)						
8 Dec 1991	17	490	10.96	3.69	8.18	2.96
30 Jan 1992	11	483	6.25	2.70	6.22	2.57
3 Mar 1992	22	490	10.96	4.54	9.55	3.71
30 Mar 1992	0	490	0	—	0	—
Cape Hatteras to Ocracoke Inlet (1,016 km^2)						
7 Dec 1991	3	283	3.55	2.65	3.53	2.46
4 Feb 1992	6	570	1.77	0.86	1.76	0.80
22 Feb 1992	42	553	17.57	8.47	12.06	6.25
9 Mar 1992	12	613	4.91	2.56	4.35	1.92
Ocracoke Inlet to 5 mi south of Drum Inlet (1,779 km^2)						
8 Jan 1992	24	517	14.29	2.50	12.28	1.72
Ocracoke Inlet to Cape Lookout (2,381 km^2)						
21 Feb 1992	14	690	6.78	1.60	6.75	1.39

* All turtles sighted, including those censored in calculations of density.

of variation were generally smaller for the strip transect estimates of density (Table 6). Turtles were present throughout the study period as far north as Oregon Inlet (Fig. 11A–E). Strip transect estimates of surface densities ranged from 0 to 12.28 turtles·100 km^{-2} (Table 6). The estimated surface density of sea turtles among areas south of Oregon Inlet did not differ substantially throughout the season north and south of Cape Hatteras (Table 6).

Overlays of turtle sightings on SST imagery indicated that turtles occurred in waters ranging from 8–24°C, but were most likely to occur in waters ≥11°C (Table 7). Sighting rates generally increased as a function of temperature. However, of 51 turtles sighted during aerial surveys for which there were same-day SST images, 10 (20%) were in waters <13°C and four (8%) were in waters <11°C (Table 7).

Table 7. Sea turtle sightings and effort in relation to sea surface temperatures on seven aerial surveys (temperature data were obtained from AVHRR imagery available from the same days as the aerial surveys)

Sea surface temperature (°C)	Number of turtles sighted	Total distance surveyed (km)	Sighting rates (turtles·100 km^{-1})
<5.0	0	101	0.00
5.0–6.9	0	182	0.00
7.0–8.9	3	505	0.59
9.0–10.9	1	234	0.43
11.0–12.9	6	455	1.32
13.0–14.9	11	520	2.12
15.0–16.9	8	359	2.23
17.0–18.9	9	277	3.25
19.0–20.9	8	187	4.27
21.0–22.9	4	74	5.38
23.0–24.9	1	34	2.98

A clear association of turtles with warm shallow waters west of the Gulf Stream was apparent in Raleigh, Onslow and Long Bays (Fig. 11A–F). Turtles were usually sighted when Gulf Stream influences or SAB water, indicated by surface temperatures ≥11°C, reached within 28 km of shore in a survey zone (5.6 km in early surveys) (Fig. 11A, B, E); turtles were not sighted when Gulf Stream influences or SAB water were offshore of the survey zone. For example, no turtles were sighted between Oregon Inlet and Cape Hatteras on 30 March when cold water (≤10°C) occupied the entire survey zone (Fig. 11F). Between 1 January and 31 March 1992, the 10°C isotherm reached nearshore waters only as far north as Oregon Inlet (Fig. 11B). Turtles frequently were sighted along strong thermal gradients (Fig. 11B, D, E).

Discussion

Turtles are poikilotherms and their distributions are generally related to water temperature (Bell and Richardson, 1978). Relatively few turtles were sighted or captured at temperatures <11°C (Table 7; Fig. 9). Sea turtles were near their reported minimal thermal tolerance in much of the area, but appeared to behave normally and were not brumating or cold-stunned. Turtles were generally active when caught (not the behavior of brumating turtles; Felger et al., 1976; Carr et al., 1980). Trawl caught turtles had been on the bottom (not the behavior of cold-stunned turtles; Schwartz, 1978) and had been feeding recently (not the behavior of brumating or cold-stunned turtles). Several studies have addressed the effects of cold water temperatures on sea turtles. The more gradual the decline in temperature, the better sea turtles appear to adapt. Loggerhead turtles exposed to a drop in temperature from 30°C to 10°C at the rate of 2.5°C·d^{-1} experienced cold stunning and floated when experimental temperatures reached 14°C (Lutz and Dunbar-Cooper, 1984; Lutz et al., 1989). Behavioral disturbances were manifested at 15°C and turtles experienced severe physiological malfunctioning at or below 10°C. In a cold study of turtles during late autumn in outdoor ponds in North Carolina, loggerheads quit feeding and floated when temperatures reached 9.0–9.5°C, Kemp's ridleys floated at 10.0–13.0°C, and green turtles floated at 9.0°C (Schwartz, 1978). Lethal temperatures for all three species occurred between 5.0–6.5°C. Green and Kemp's ridley turtles were exposed to declining temperatures (5–6°C·2wk^{-1}) under controlled conditions in indoor facilities (Moon, 1992). The

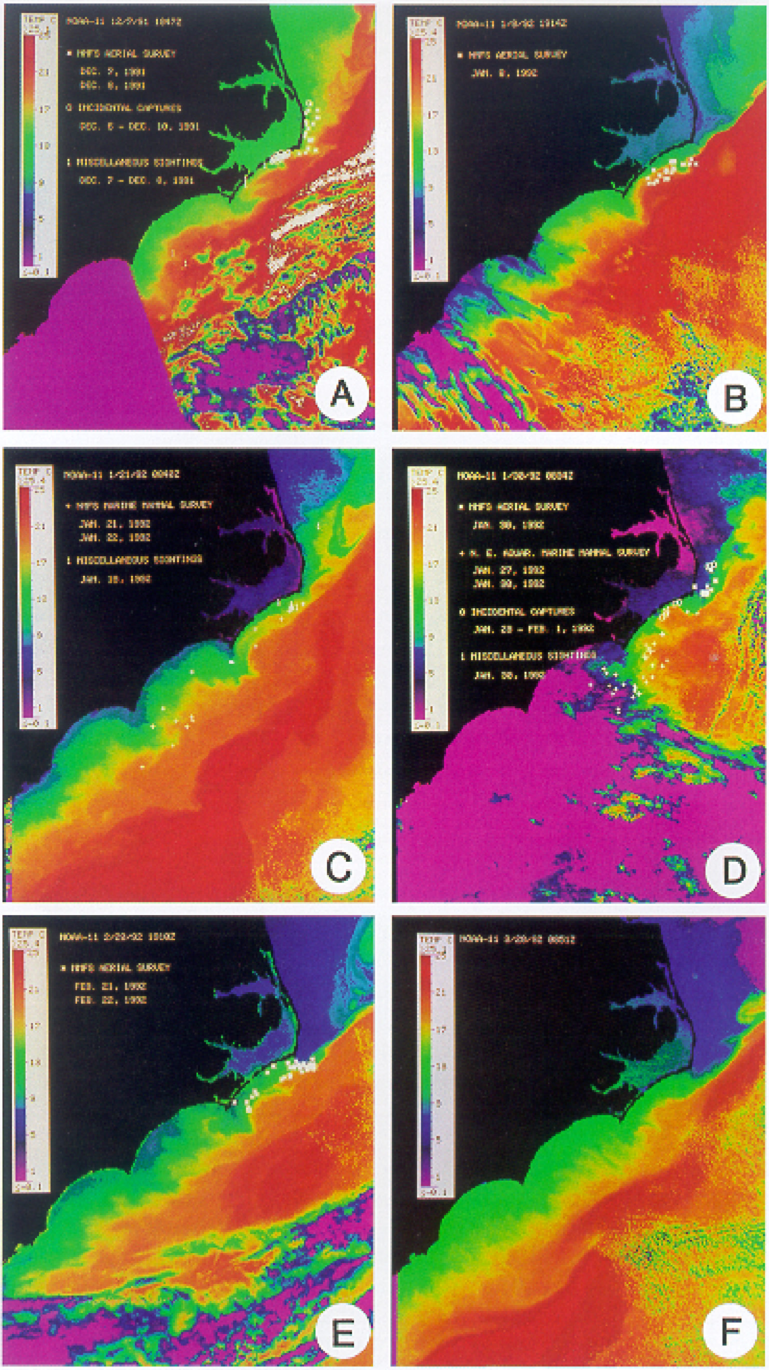


Figure 11. Satellite images of sea surface temperature between Cape Charles, Va. and Cape Romain, S.C., and sightings of sea turtles in North Carolina waters. Magenta areas are cloud cover. White areas denote temperatures >25.3°C. Turtle sightings from NMFS aerial surveys are denoted with '*', sightings from marine mammal surveys are denoted with '+', captures by flounder trawl vessels are denoted with '○', and miscellaneous sightings are denoted with '1'. See Figure 1 for references made to

turtles stopped feeding when water temperatures dropped to 15°C, and were semi-dormant on the bottom at temperatures of 9–15°C. They never appeared cold-stunned or floated within the range of experimental temperatures (8.7–26°C), but one Kemp's ridley died after 2 d at 8.7°C.

The Gulf Stream has considerable influence on sea turtle distributions. Thompson (1984) sighted turtles in offshore waters to the west of the Gulf Stream in winter aerial surveys of the SAB south of Cape Fear, but found them generally absent in nearshore waters where cold fresh water, discharged from inlets, mixed with coastal waters. Hoffman and Fritts (1982) noted that, in August, turtles off eastern Florida were aggregated just west of the Gulf Stream. They hypothesized that turtles actively avoided the Gulf Stream in fall to prevent being transported northward, but sought areas where warm waters associated with the western wall of the Gulf Stream, occurred over relatively shallow areas (<70 m) of the continental shelf. A similar hypothesis may explain the presence of turtles in winter in the vicinity of Cape Hatteras.

The entire SAB is affected by the warm, fast-moving Gulf Stream and its frontal eddies that impinge upon and override the continental shelf. In the SAB, the density gradient between nearshore waters and Gulf Stream water is temperature-dominated (the salinity component is small) (Lee et al., 1981; Pietrafesa et al., 1985) and is strongest in winter. Strong wind mixing causes SAB shelf waters to be isothermal in the winter (Pietrafesa et al., 1985). Gulf Stream waters override the narrow continental margin in the vicinity of Cape Hatteras, and characteristically, the surface waters of Raleigh Bay are far warmer in the winter than bays to the south where continental margins are >90 km wide (Churchill and Cornillon, 1991; Tester et al., 1991).

Two different episodic, physical processes dominate in the area. One brings warm water ashore and the other flushes warm water out of the area. The first is a shoreward movement of the Gulf Stream front in the form of frontal eddies. These consist of anticyclonically flowing eddy "crests" of near-surface Gulf Stream water, 15–20 m deep, which can extend to the shore (Pietrafesa, 1989).

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landmarks, inlets, and water bodies, and Table 1 for references to NMFS surveys. A) SST image 7 December 1991. NMFS aerial surveys were conducted between Oregon Inlet and Ocracoke Inlet. Sea turtles were sighted and caught in warm waters which reached the beach, both north and south of Cape Hatteras. Sightings and captures occurred as far north as the Wimble Shoals area. B) SST image 8 January 1992. A NMFS aerial survey was conducted between Ocracoke Inlet and Drum Inlet. Sea turtles appeared associated with the strong thermal gradient in Raleigh Bay, south of Ocracoke Inlet. Note the absence of sightings immediately adjacent to the beach where temperatures were approximately 9–10°C. C) SST image 21 January 1992. Sea turtles were sighted during the marine mammal survey conducted between Cape Hatteras and Cape Fear. The Gulf Stream is farther offshore in the southern area of the survey and the nearshore waters are cold. The distribution of sea turtles paralleled that of the Gulf Stream waters over the continental shelf. Note the presence of Gulf Stream water on the shelf north of Cape Hatteras and the sighting of a sea turtle north of Oregon Inlet. D) SST image 30 January 1992. Sea turtles were sighted during the marine mammal survey conducted over Raleigh Bay and northern Onslow Bay and during the NMFS aerial survey between Oregon Inlet and Cape Hatteras. Temperatures south of Cape Lookout appear cool due to cloud cover. Turtles appear associated with Gulf Stream waters and appear farther from shore in Onslow Bay and southern Raleigh Bay. Note the capture and sighting of sea turtles in relatively cold water north of Cape Hatteras. E) SST image 20 February 1992. NMFS aerial surveys were conducted between Cape Hatteras and Cape Lookout. Sea turtles were especially abundant along the strong thermal gradient between the Virginia Coastal Water and the waters of the Gulf Stream. F) SST image 28 March 1992. No sea turtles were sighted during an aerial survey conducted 2 d after this image between Oregon Inlet and Cape Hatteras. Note the presence of cold Virginia Coastal Water throughout the entire area surveyed following a period of sustained northerly winds (see Fig. 13).

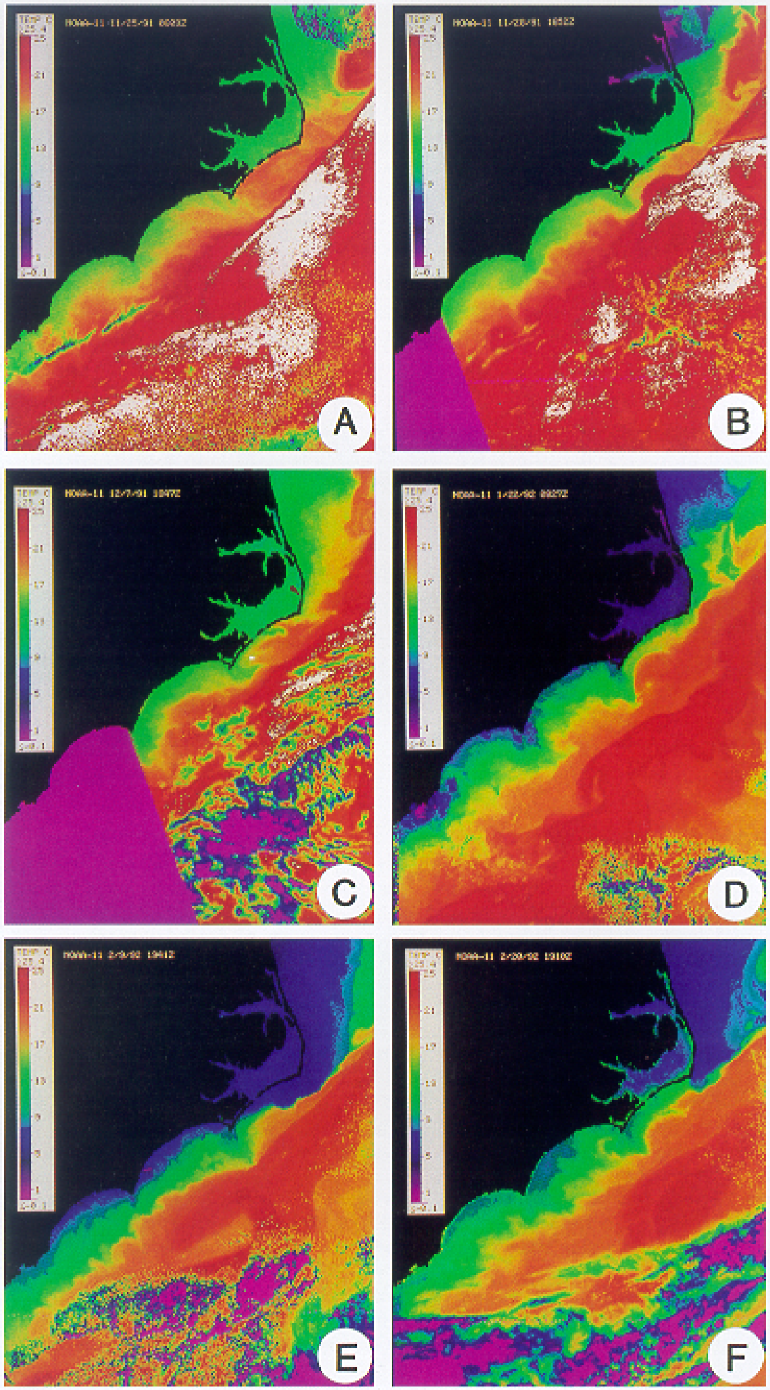

Figure 12. Satellite images of sea surface temperature between Cape Charles, Va. and Cape Romain, S.C. The advanced, very high resolution radiometer was flown on the NOAA-11 polar-orbiting satellite. Magenta areas are cloud cover. White areas denote temperatures >25.3°C. See Figure 1 for references made to landmarks, inlets, and water bodies. A) SST image 25 November 1991. The western

These density-driven features vary in intensity and amplitude and have their greatest effect where the continental shelf is the narrowest (e.g., the Carolina Capes region, where the shelf is the narrowest north of Cape Canaveral). Occurring in the time scale of 2–14 days (Lee et al., 1981), frontal eddies can introduce warm water (20–25°C) directly into the nearshore waters of Raleigh Bay (Glenn and Ebbesmeyer, 1994). These features can be recognized easily from SST images (Fig. 12A, "normal" conditions with Gulf Stream flowing at the edge of the continental shelf and warm surface water in Raleigh Bay; Fig. 12C, a very strong intrusion of the western edge of the Gulf Stream into Raleigh Bay; Fig. 12D, filaments of very warm (Gulf Stream) water override the entire continental shelf of Raleigh Bay influencing the nearshore waters adjacent to the barrier islands). The second episodic process is wind. In winter, strong winds from the north and northeast push cold low salinity water (Virginia Coastal Water) from the MAB around Cape Hatteras and along the nearshore to outer shelf areas of Raleigh Bay (Fig. 12E; Pietrafesa et al., in press). Generally, the winds must be sustained from the north for this event to occur to any great extent (Pietrafesa, 1989; Pietrafesa et al., in press; Fig. 13). After the northerly winds subside, the Gulf Stream water once again can override the surface waters of Raleigh Bay (Fig. 12F).

The Gulf Stream deviates from its coast-parallel course at Cape Hatteras, but Gulf Stream water often does reach the shelf and upper slope of the MAB (Fig. 12B). It has been found 25–27% of the time between 50–115 km north of Cape Hatteras (Churchill and Cornillon, 1991). Gulf Stream water is significantly less dense than MAB slope water of equivalent depth; consequently, the circulation associated with this density contrast acts to advect MAB shelf water seaward at the northern margin of discharged Gulf Stream water (Churchill and Cornillon, 1991). While this process is operative on the slope, the presence of Gulf Stream water on the shelf does not alter density gradients or near-bottom flow on the shelf significantly. Shelf waters to the north of Cape Hatteras are generally isothermal in the winter because of strong wind mixing and convective mixing resulting from surface cooling (unpublished MARMAP data[2]).

The oceanographic processes described above are well documented (Pietrafesa et al., 1985, in press; Tester et al., 1991; Churchill and Cornillon, 1991; Fig. 12), occur throughout every winter, and influence the distribution of sea turtles. Favorable temperature and depth regimes for sea turtles occur along the western edge of the Gulf Stream throughout the winter in the vicinity of Cape Hatteras and southward throughout the SAB. Where the continental shelf is narrow, par-

[2] Data were collected 1977–1987 by the National Marine Fisheries Service as part of the Marine Resources, Assessment, and Prediction (MARMAP) program. Examination of temperature and salinity profiles from the 11 southernmost MARMAP stations, located between the mouth of the Chesapeake Bay and Cape Hatteras, revealed that the waters were generally isothermal in the winter.

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edge of the Gulf Stream is parallel to the edge of the continental shelf and is depicted as dark red (lower left to upper right diagonal). B) SST image 28 November 1991. Early stage of Gulf Stream meander. The outpocketing of the western edge of the Gulf Stream is evident in Raleigh Bay. C) SST image 7 December 1991. Late stage of Gulf Stream meander. Filaments of Gulf Stream water override the cold, dense shelf water and penetrate the entire width of the shelf, reaching nearshore waters. D) SST image 22 January 1992. Note the presence of Gulf Stream water (>5°C higher) on the continental shelf north of Cape Hatteras. E) SST image 9 February 1992. Virginia Coastal Water (5°C) has been pushed around Cape Hatteras and into Raleigh Bay by strong winds from the north and northeast (see Fig. 13). The Gulf Stream is forced away from Cape Hatteras. F) SST image 20 February 1992. Upon relaxation of northerly winds (see Fig. 13), Virginia Coastal Water is less evident in Raleigh Bay. The Gulf Stream is now closer to Cape Hatteras.

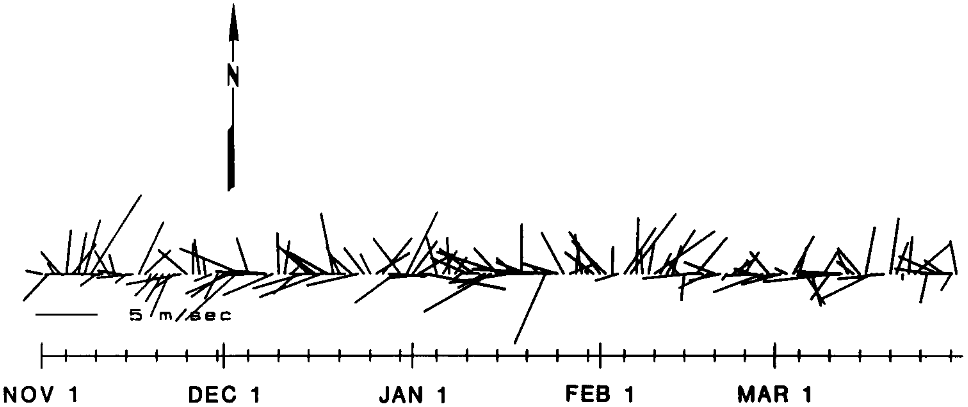

Figure 13. Daily mean wind speed and direction recorded at National Weather Service station in Buxton, N.C. (Cape Hatteras), from 1 November 1991 through 31 March 1992. Vectors indicate the direction from which the wind was blowing.

ticularly in Raleigh Bay and northward to Oregon Inlet, these favorable conditions occur in nearshore waters as well. The narrowness of the continental shelf and the potential influence of the Gulf Stream on these nearshore regions serve to concentrate sea turtles emigrating from the MAB and Pamlico and Core Sounds (Fig. 1). Thus, sea turtles can be at greater risk for possible interaction with fishing activity on the continental shelf near Cape Hatteras during the winter than in any other area in the SAB. In this area, the farther offshore and the farther south fishing activity occurs, the more likely the waters fished will be influenced by the Gulf Stream and the more likely that turtles will be encountered.

Sea turtles were captured by the flounder trawl fishing fleet in the vicinity of Cape Hatteras November 1991–February 1992 (Fig. 11A, D), and strandings records indicate that summer flounder fishery/turtle interactions probably occurred in the past (Magnuson et al., 1990). The species composition of turtles captured in the trawls was different from that reported for inshore populations in North Carolina, Virginia and New York (Epperly et al., in press-b). Most notable was the greater relative abundance of Kemp's ridleys, which accounted for 60% of the November–December 1991 catch south of Cape Hatteras, and for 36% of the overall catch throughout the monitoring period. Small Kemp's ridleys (<30 cm OCCL), characteristic of those found off New York during the summer (Morreale et al., 1992) and generally absent from North Carolina inshore waters (Epperly et al., in press-b), were a component of the observed ridley catch. Thus, the captured Kemp's ridleys probably represent the mixing of animals migrating out of the New York Bight with those leaving Chesapeake Bay and Pamlico and Core Sounds. Green turtles were less abundant in the flounder trawl fishery catches than would have been predicted from their representation in North Carolina and New York inshore waters.

The overall turtle catch rate for the entire flounder trawl fishery operating south of Cape Charles (4.8 turtles$\cdot$100-h^{-1} of towing) is similar to values reported for the Atlantic shrimp fishery by Henwood and Stuntz (4.9; 1987), Renaud et al. (3.0; 1990), and Renaud et al. (3.8; 1991), but is much lower than 56$\cdot$100-h^{-1} reported for the Cape Canaveral ship channel (Butler et al., 1987). Area specific catch rates, however, were as high as 17 turtles$\cdot$100 h^{-1} towing south of Cape Hatteras during November–December. This catch rate is comparable to the 24 turtles·100-h^{-1} (14·100-h^{-1} for loggerheads turtles + 10·100-h^{-1} for Kemp's ridley turtles) obtained by NCDMF during 54-h of experimental tows in December 1990 in the same area [standardized rates were calculated from data presented in Monaghan (1991) and NCDMF (1991)].

Catch rates of turtles in the flounder trawl fishery differed greatly north and south of Cape Hatteras (Table 4), but surface densities of turtles south of Oregon Inlet, determined by aerial surveys, did not appear to differ substantially north and south of Cape Hatteras (Table 6). Surface densities for a survey area were as high as 12.28 turtles·100 km^{-2}, using the strip transect method of analysis (Table 6). Aerial surveys were flown in the study area on 11 December 1990, 15 November 1991 and 21 January 1992 by the Virginia Institute of Marine Science (Musick et al., 1992; Keinath, 1993). Turtles were sighted throughout the area in the November 1991 survey and surface densities ranged from 2.4–15.6 turtles·100 km^{-2} (Keinath, 1993). In the January 1992 survey, turtles were sighted in the vicinity of Cape Hatteras and southward; surface density was 1.2 turtles·100 km^{-2} (Keinath, 1993). In the previous season, surface densities for individual transects flown between Oregon and Ocracoke Inlets in December 1990 were as high as 30.6 turtles·100 km^{-2} (mean densities were not reported) (Musick et al., 1992). Surface turtle densities in the area are greater than mean winter densities in surface waters between Cape Fear and Key West, Florida where densities ranged from 0.02–3.71 turtles·100 km^{-2} and averaged 0.18 (Thompson, 1984[3]). The surfacing behavior of overwintering turtles is poorly documented. Sea turtles spend 4–41% of their time on the surface (Kemmerer et al., 1983; Byles and Dodd, 1989). Three telemetered loggerheads migrating southward along the North Carolina coast during fall and early winter stayed on the surface but 10.6% of the time (Keinath, 1993). Thus, the estimated number of sea turtles on the surface represents a small fraction of the turtles in the area.

Tow time restrictions (60 min on bottom and 75 min total) were implemented in the summer flounder trawl fishery off Virginia and North Carolina during the fall of 1991 to reduce sea turtle mortalities associated with the flounder fishery. A strong positive relationship had been demonstrated between tow duration and the incidence of turtle mortalities in the shrimp fishery (Henwood and Stuntz, 1987), and Magnuson et al. (1990) had recommended that tows in cold water be restricted to a maximum of 60 min on the bottom. Despite low compliance with the tow time restrictions (26%), the death rate of trawl-caught turtles (8.6%) was less than that reported for an unregulated shrimp fishery (23.4%) (Henwood and Stuntz, 1987). In general, tow times were shorter for hauls during which turtles were caught or expected to be caught (51% were less than 1.3-h and 94% were less than 2-h). Thus, the relatively few turtle mortalities observed (5) were attributable, in part, to fishermen reducing tow times in areas where turtle densities were high (e.g., Hatteras Bight), and to the presence of observers trained to resuscitate comatose turtles. Although few turtle mortalities were documented during the flounder trawl fishery, the number of turtles requiring resuscitation following 60-min tows (actual time on bottom) was relatively high (4 of 30 turtles) (Fig. 10). On one trip during which total tow times never exceeded 75 min, the proportion resuscitated was 0.17 (4 of 23 turtles), one turtle died, and two previously dead turtles were caught. High rates of resuscitation and a death in short tows suggest the presence of stressed animals, perhaps due to multiple captures of individual turtles in combination with relatively warm water temperatures. Mul-

[3] Thompson (1984) reported total densities (surface and submerged turtles), adjusting surface densities by assuming turtles were on the surface 3.8% of the time (Kemmerer et al., 1983). We have compared her surface density estimates.

tiple captures increase physiological stress by depriving turtles of sufficient time to recover (Lutz and Dunbar-Cooper, 1987; Stabenau et al., 1991), and oxygen demands increase with increasing water temperatures (Lutz et al., 1989; Moon, 1992). The capture of two previously dead turtles in the same fishing area is suggestive of intense trawling effort in a relatively small area. Throughout the study, observers reported as many as 30 other vessels trawling within sight of their vessel during a 24-h period. Directed overflights confirmed that trawlers were generally aggregated. Like Henwood and Stuntz (1987), we assumed that resuscitated turtles lived, but Magnuson et al. (1990) reviewed some evidence to the contrary. Thus, if all resuscitated turtles later died, or if other fishermen failed to attempt resuscitation on comatose turtles, the death rate in the summer flounder trawl fishery could have been twice that observed and include an estimated 56 dead Kemp's ridleys (Table 5). As stated earlier, at least one resuscitated and tagged turtle survived to be recaptured in the Chesapeake Bay the following summer.

At-sea monitoring demonstrated that, during the winter, the catch of sea turtles by the trawl fishery for summer flounder off North Carolina was great (>1,000 turtles estimated caught), that the proportion of Kemp's ridley turtles in the catch was relatively high (35%), and that under tow time restrictions nearly 20% of the turtles were estimated to be comatose or dead (181). These observations, along with evidence that physical processes influence the distribution of sea turtles in the winter in the vicinity of Cape Hatteras and that favorable conditons can occur throughout every winter, are the primary reasons sea turtle conservation regulations are needed for this fishery.

Acknowledgments

Monitoring of the summer flounder fishery was greatly enabled by a large number of individuals, in particular those owners and captains that voluntarily carried observers. We thank the 21 observers, including those of the North Carolina Division of Marine Fisheries (NCDMF), the individuals in the NMFS Northeast Fisheries Science Center and the NCDMF for coordinating observers, and the individuals in the NMFS Northeast Region office who coordinated vessel assignments during the period of mandatory coverage. The U.S. Coast Guard, Group Cape Hatteras was an integral participant throughout the period, conducting overflights, relaying information daily from observers aboard trawlers, and ferrying additional tags to observers offshore. The efforts of D. Barnard and J. Keinath in conducting timely necropsies were greatly appreciated. K. Harris of NMFS Beaufort Laboratory provided port agents' data on trips landed. The NCDMF conducted overflights along the beach. NMFS flights were supported by the NOAA Aircraft Operations Center, the N.C. Forestry Service, Aero-Marine Surveys, and Brady Aviation Consultant. Turtle sightings from marine mammal surveys were provided by the New England Aquarium (S. Kraus; Minerals Management Service contract 14-35-0001-30486) and NMFS Miami Laboratory (W. Hoggard). Near real-time satellite imagery of sea surface temperatures was provided to the NMFS Beaufort Laboratory by the NOAA Coastal Ocean Program's CoastWatch Project. We thank J. DeCampo for facilitating our use of the imagery. Wind data were provided by the NOAA National Weather Service office in Buxton, N.C. MARMAP data were provided by J. Churchill and J. Manning. The NMFS Office of Protected Resources provided the financial support for this effort. We thank C. Lewis for many of the illustrations. The manuscript was greatly improved by the reviews of J. Churchill (WHOI), D. Colby (NMFS), C. Manooch, III (NMFS), L. Mercer (NCDMF), J. Musick (VIMS) and C. Peterson (UNC).

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